Ground Moving Target Tracking and Exploitation Performance Measures

Jon Jones

Air Force Research Laboratory/IFEA
phone: 315-330-1665
email: jon.jones@rl.af.mil

Jeff Brandstadt, Mark Kozak, Tim Hughes, and Mike Blount

Black River Systems
email: brandsta@brsc.com
email: {mpkozak, hughest, blount}@ifea.rl.mil

Abstract Ground Moving Target Indication provides a unique source of information for the exploitation of surface and low flying aircraft at long range, in all weather, providing situation awareness, targeting, and intelligence information. While airborne moving target indication and fire control radars have been around for a long period of time, it has been only the last decade when Ground Moving Target Indication (GMTI) data has been collected and used to prosecute mobile surface targets. This presentation addresses the use of GMTI data from providing intelligence information to the analysis and leads to the challenges associated with doing long-term track maintenance. The intelligence community has been expressing interest in GMTI data since 1999 when investments were made to develop the first exploitation capability that focused on products from Joint STARS GMTI data providing a web based capability to process and exploit Joint STARS data via a Network Centric Architecture. At the same time, DARPA and AFRL were pursuing the Long Term Track Maintenance challenge performing multi-platform command and control, horizontally fusing multiple sensors with weapons for a long-range precision fire control system. The focus of this presentation is to cover performance metrics. The metrics will be associated with operators-in-the-loop evaluations looking at intelligence and analysis for the find, fix, track, and assess portion of the weapon. The second set of metrics focus on long-term track maintenance evaluations. Track accuracy and persistence in time critical targeting, which address the track, target, and engage portion of the weapon chain. Programs to be discussed include the Moving Target Information Exploitation System (MTIX) program with respect to intelligence products, the Multi-Platform Tracking Exploitation (MPTE) and the Affordable Moving Surface Target Engagement (AMSTE) programs with respect to Long Term Track Maintenance and Precision Fire Control.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **20 DEC 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Ground Moving Target Tracking and Exploitation Performance Measures**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory/IFEA**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **See also, ADM001741 Proceedings of the Twelfth Annual Adaptive Sensor Array Processing Workshop, 16-18 March 2004 (ASAP-12, Volume 1)., The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**23**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Air Force Research Laboratory
Information Directorate

Ground Moving Target Tracking and Exploitation Performance Measures
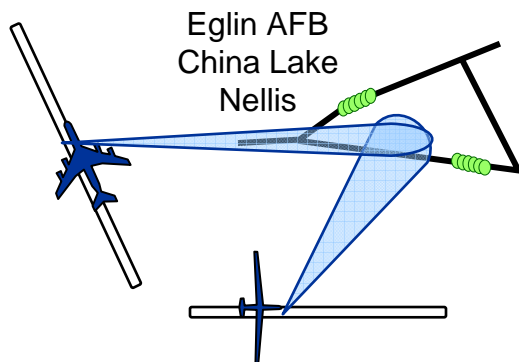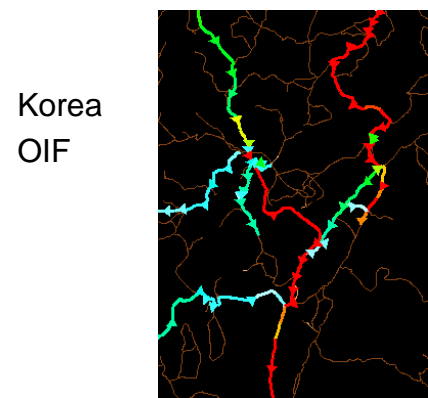
17 March 2004

Jon Jones

Jon.Jones@rl.af.mil

Fusion Technology Branch

Air Force Research Laboratory

Phone: 315-330-2923

Outline

Multi-Platform Tracking & Engagement

Eglin AFB
China Lake
Nellis

Korea
OIF

Flow Analysis
MTI Change Detection

- **Ground Moving Target Tracking**

  - **Performance Measures for Tracking Targets**

  - **Sources of Analysis**

    - **Multi-Platform Tracking Exploitation (MPTE)**

    - **Affordable Moving Surface Target Engagement (AMSTE)**

  - **Well Defined Metrics**

- **Ground Moving Target Exploitation**

  - **Exploitation MOPs/MOEs (use of the data and performance of the systems)**

  - **Moving Target Information Exploitation (MTIX) Features**

    - **OIF, Korea, DCGS**

  - **Metrics Maturing**

Indicators of Association Complexity

1) Normalized Target Density – Number of detections competing for association.
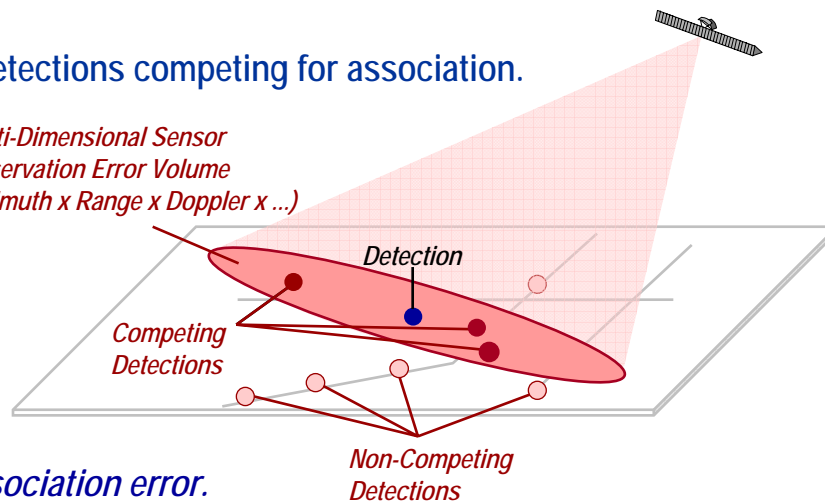
Dependencies
- **Observation Error Volume**
  - Dimensionality
  - Measurement Errors (σ)
  - Vehicle/Sensor/ROI Geometry
  - Sensor distance from ROI
- **Number of Nearby Confusers**
  - Density of Targets
  - False Alarm Rate
  - False/Branch Track Rate

Multi-Dimensional Sensor Observation Error Volume (Azimuth x Range x Doppler x ...)

Detection

Competing Detections

Non-Competing Detections

NTD quantifies the measurement error contribution to association error.

2) Gap Time – Time between a target's detections. (Amount of time to extrapolate track and track error.)
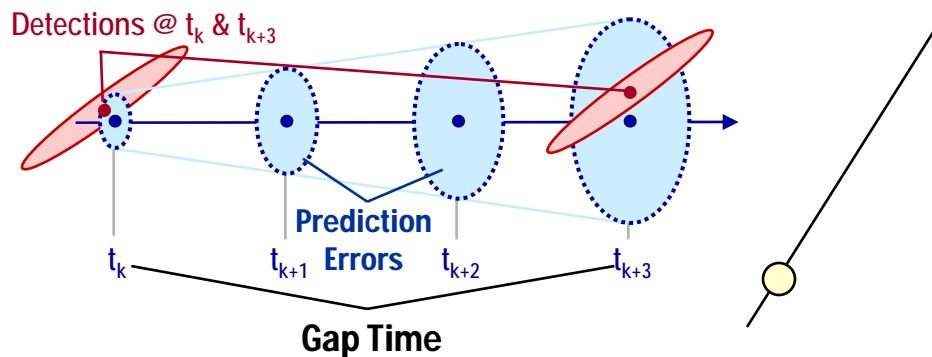
Dependencies
- **Sensor**
  - Revisit rate
  - Probability of Detection
  - Clutter cancellation technique (MDV)
  - Sensor availability
- **Environment**
  - Terrain blockage
  - Target speed relative to mainlobe clutter
  - False/branch track rate

Detections @ t_k & t_{k+3}

Prediction Errors

t_k t_{k+1} t_{k+2} t_{k+3}

Gap Time

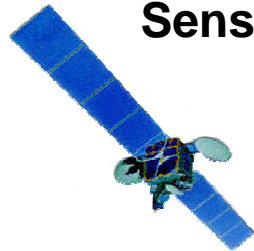*Gap Time quantifies the prediction error contribution to association error.*

AMSTE managed this asymetrically (revisits when needed)

System of Systems designs must drive down Gap Time and Normalized Target Density

3

Operator-In-The-Loop Experimentation

Sensor Configurations

21 Ball Low Earth Orbit Constellation

8 Ball Wolf Pack 8/1/1

10 Ball Mid Earth Orbit Constellation

Scenario Volume

160 Vehicle "Davison Challenge"	140 Vehicle Korea
2 Convoys plus background traffic	4 Convoys plus background traffic
10,000 Vehicle RT-1	15,000 Vehicle RT-2
25 Convoys plus background traffic	34 Convoys plus background traffic

Experience Operators
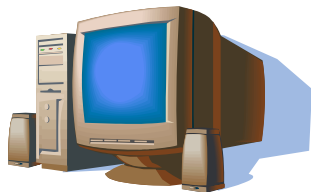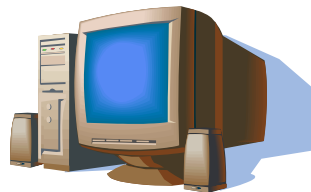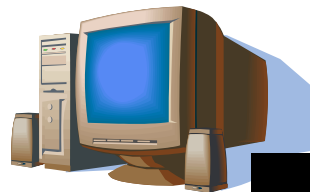
Metrics

Link 16 Messages

Recorded for Post Processing

MTIX
Operator
Auto Assisted Tracker

JSWS
Operator
No Auto Tracking

MATrEx
Operator
Auto Only Tracker
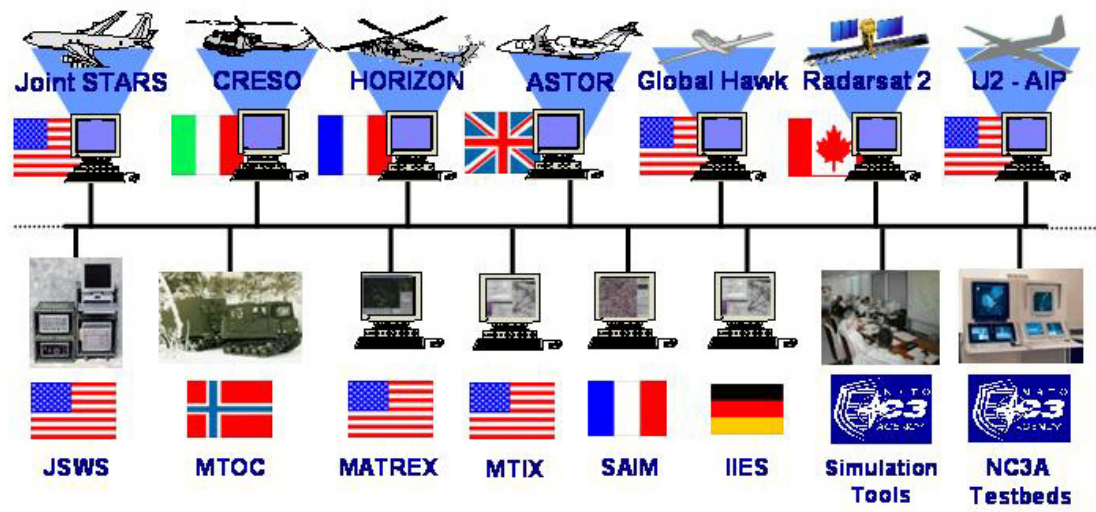
Border Crossings

Convoy Following

Volume of Coverage

Tracklets

AFRL Developed Simulations, Models, and Metrics

4

Simulation Exercise

October 2003 Exercise

Location: NC3A The Hague, NE

Experience Army and AF Operators

Robust 2 Week Scenario

NC3A Dev. Hostile & Friendly Targets

AFRL Dev. Civilian Targets

TTPs and CONOPS

Operators Nominated Link 16

Use of J3.5 Message Set

AFRL SETUP

DIS PDU Lan.
NATO Ex Lan.

Global-Hawk Sim, FTI program (PC/Linux)

U2-AIP Sim (PC/Linux)

CSP, GVS Playback, Data Logger (Sun/Solaris)
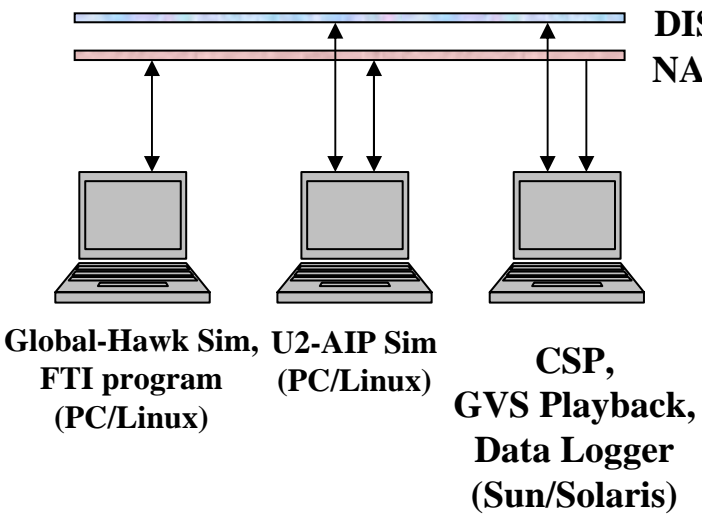
Data logged for post analysis:
All DIS entity states
 - **PDU timestamp vs. time received**
 - **Compressed and stored as NRTTDF**
• **All NatoEx GMTI, FreeText, and RSRs**
• **All JTIDS J2.2 (Ownship) and J3.5 (Track) messages**

5

Total GMTI reports – all sensors
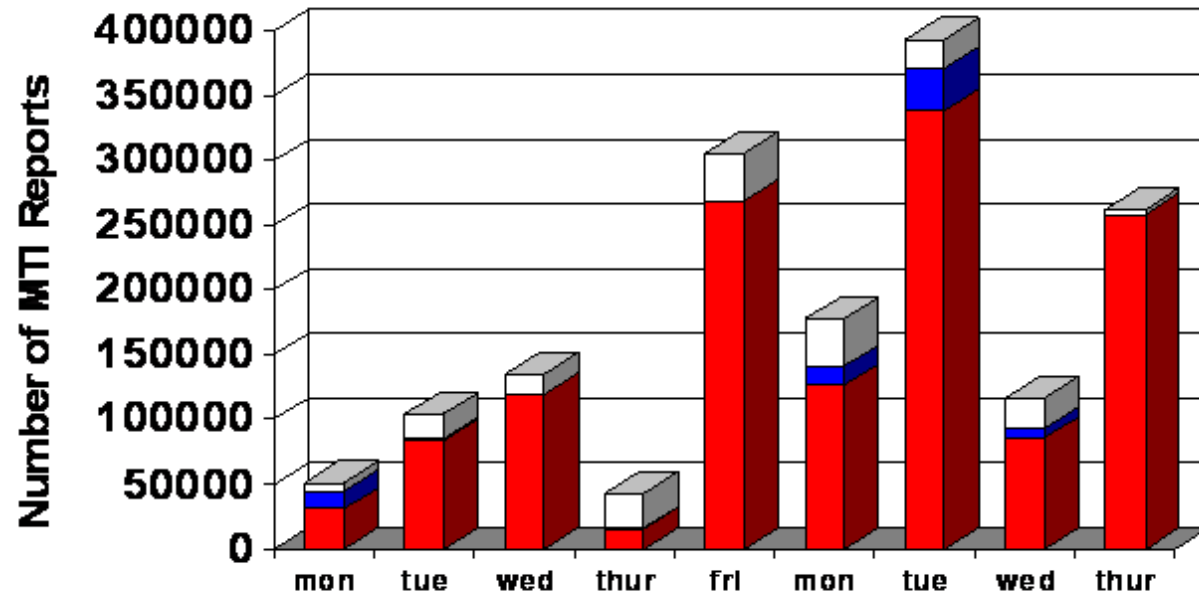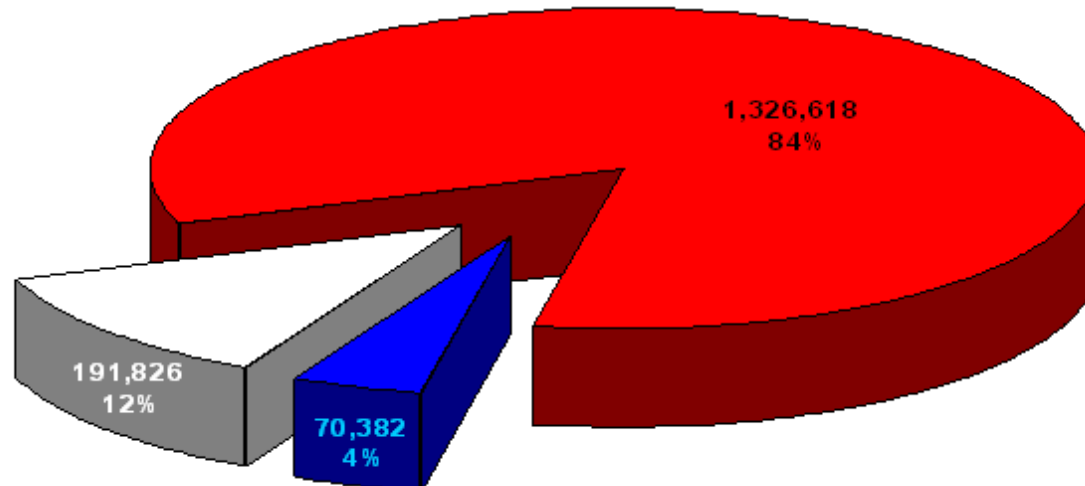

- GMTI on Civilians
- GMTI on Friendlies
- GMTI on Hostile Targets

•Based on all sensor data combined

•Does not include false alarms or MTI on airborne targets

Total 1.5+ million GMTI reports

Does not include MTI that did not associate with ground targets.

Based on truth id set by sensor simulations.

1,326,618
84%

191,826
12%

70,382
4%

Total GMTI per sensor

871,039
55%

413,091
26%

4%

2%   3%   4%   6%

All Ground Targets

Legend:
- VSTARS
- U2AIP
- RADSAT
- HORIZON
- HALE
- G-HAWK
- CRESO
- ASTOR
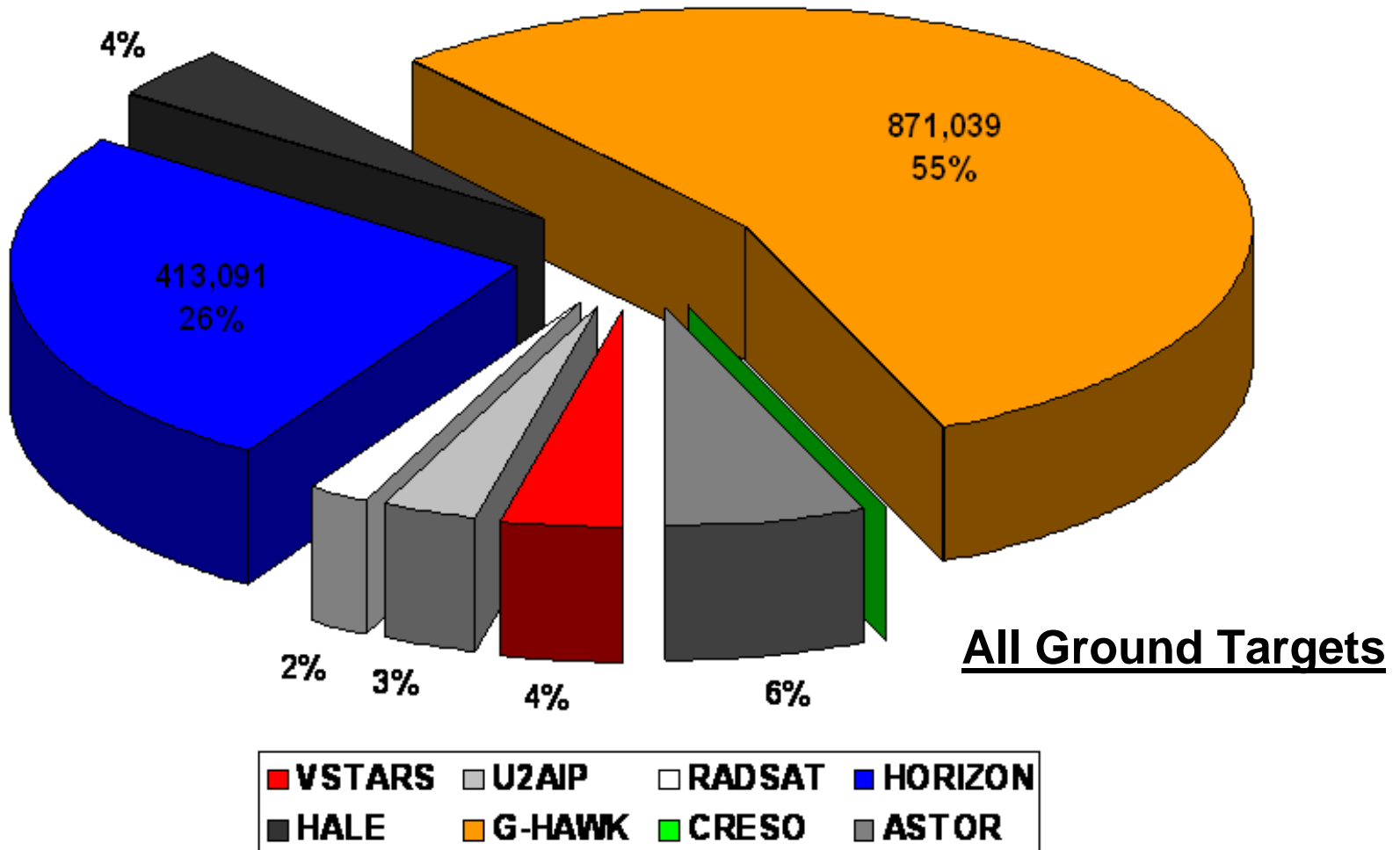
MTI on ground targets only.
Does not include false alarms or MTI on airborne targets.
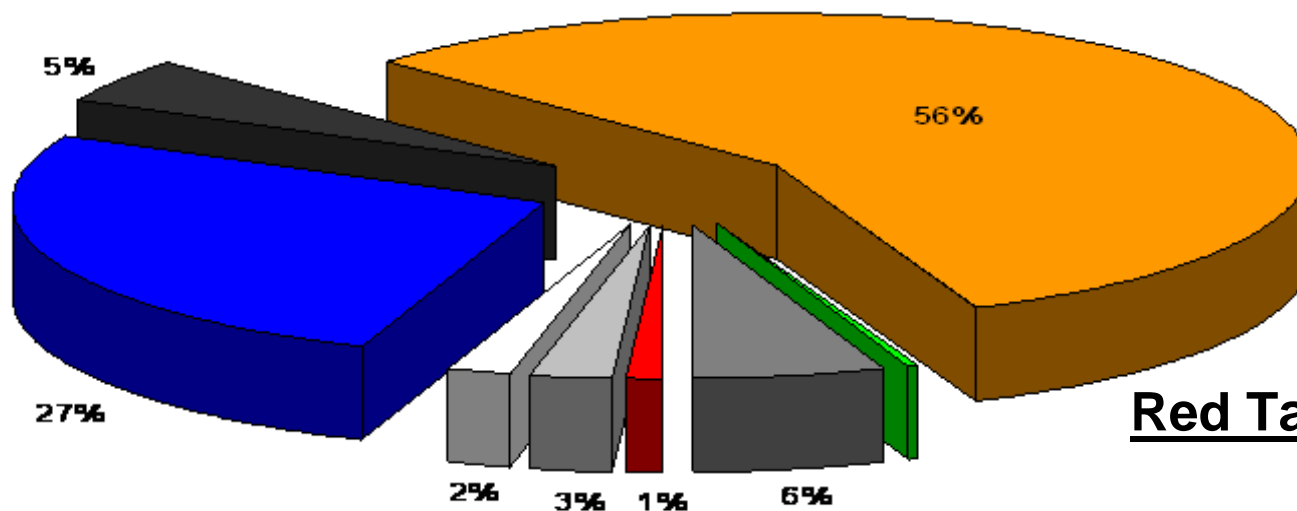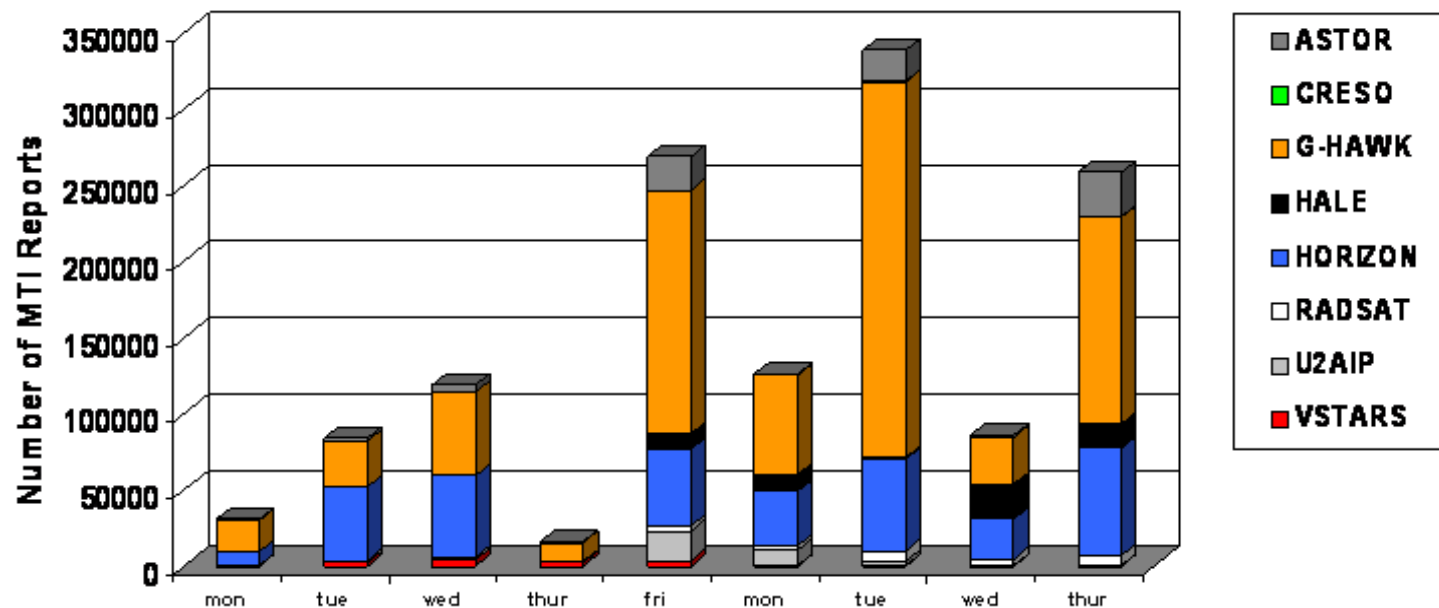
Red Targets Only

Targets Detected by GMTI Radar

Chart: "Number of Unique Targets" (y-axis, 0 to 1200) vs. days (x-axis: mon, tue, tue, wed, thur, thur, fri, fri, mon, tue, tue, wed, wed, thur)

Legend:
- ☐ Confusers Visible
- 🟦 Friendly Targets Visible
- 🟥 Hostile Targets Visible
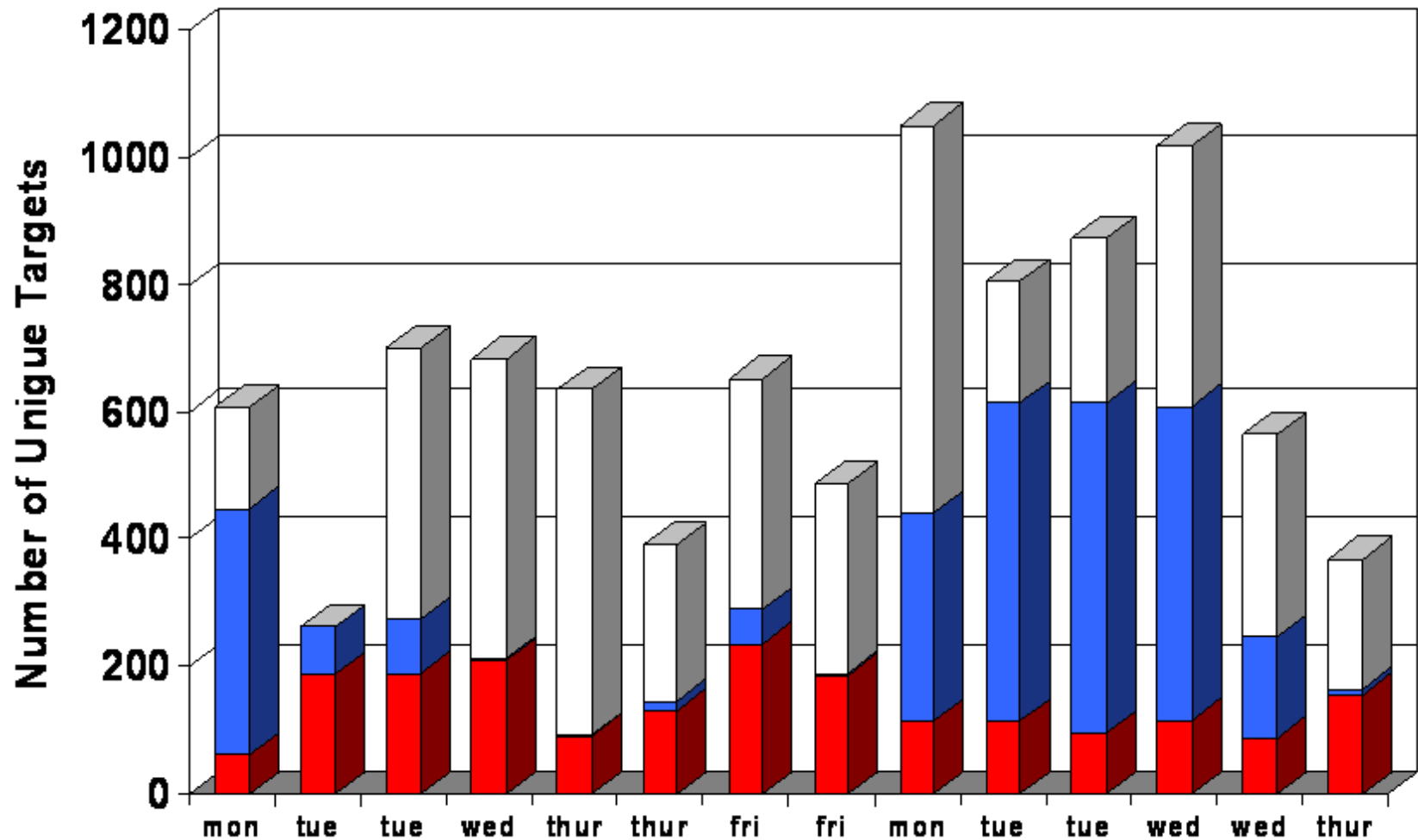
Based on all sensors combined.
Ground targets only.
Some runs are divided into AM/PM segments.

9
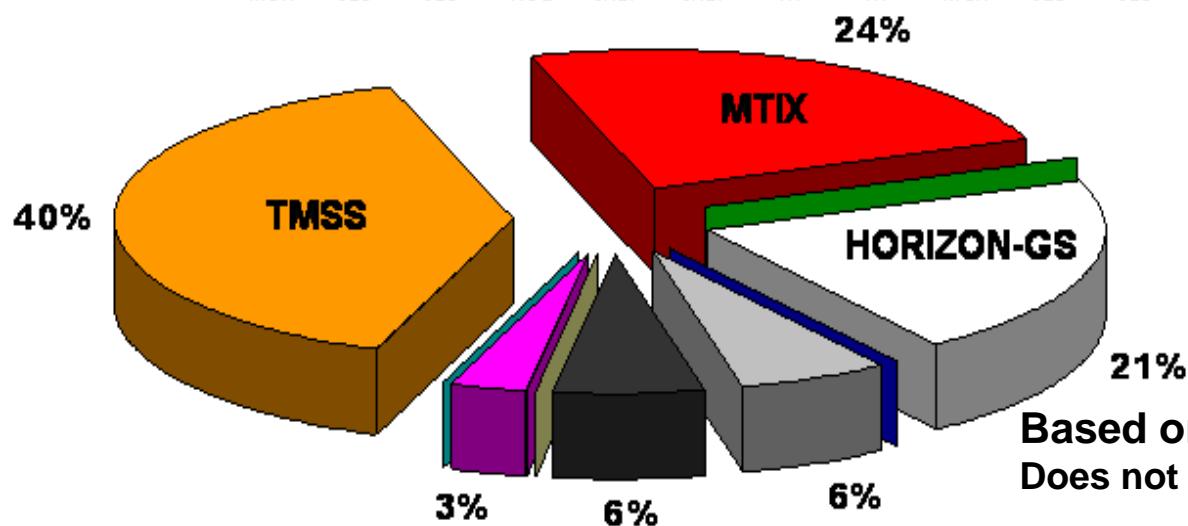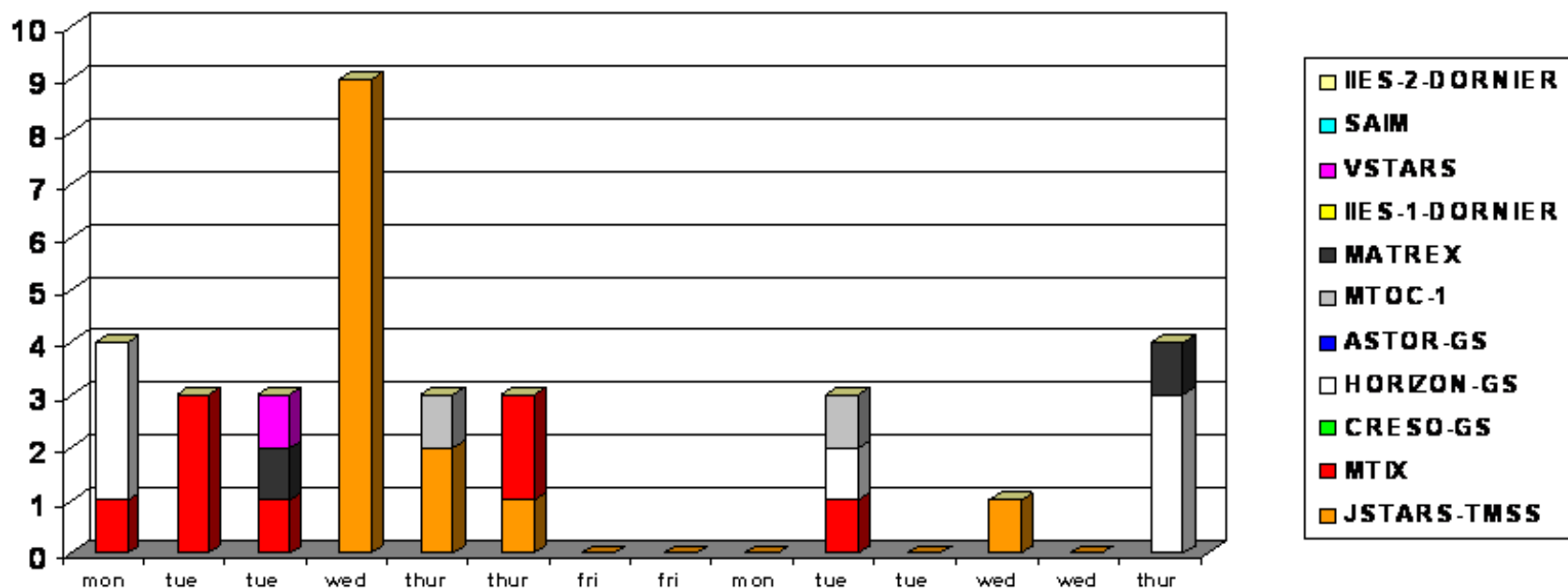
Tracks on Red Targets Only

Based on J3.5 on red targets only
Does not consider re-use of track ids per run/day

1.08 Minutes average across all J3.5 Tracks on red targets

Track Updates are Today Performed through Voice Updates

Operator/Track Metrics Summary

- **Current Army and Air Force Operators are use to Joint STARS**
  - •**There was an Operator Dependency on Joint STARS**

- **During the second week, operators tracked mostly friendly targets**
  - -Difficulty with Intel given to operators or IPB ?

- **Track ID lifetimes averaged slightly more than 1 minute**
  - •**Not Unexpected, current CONOPS and tools do not allow for Continuous Updates**
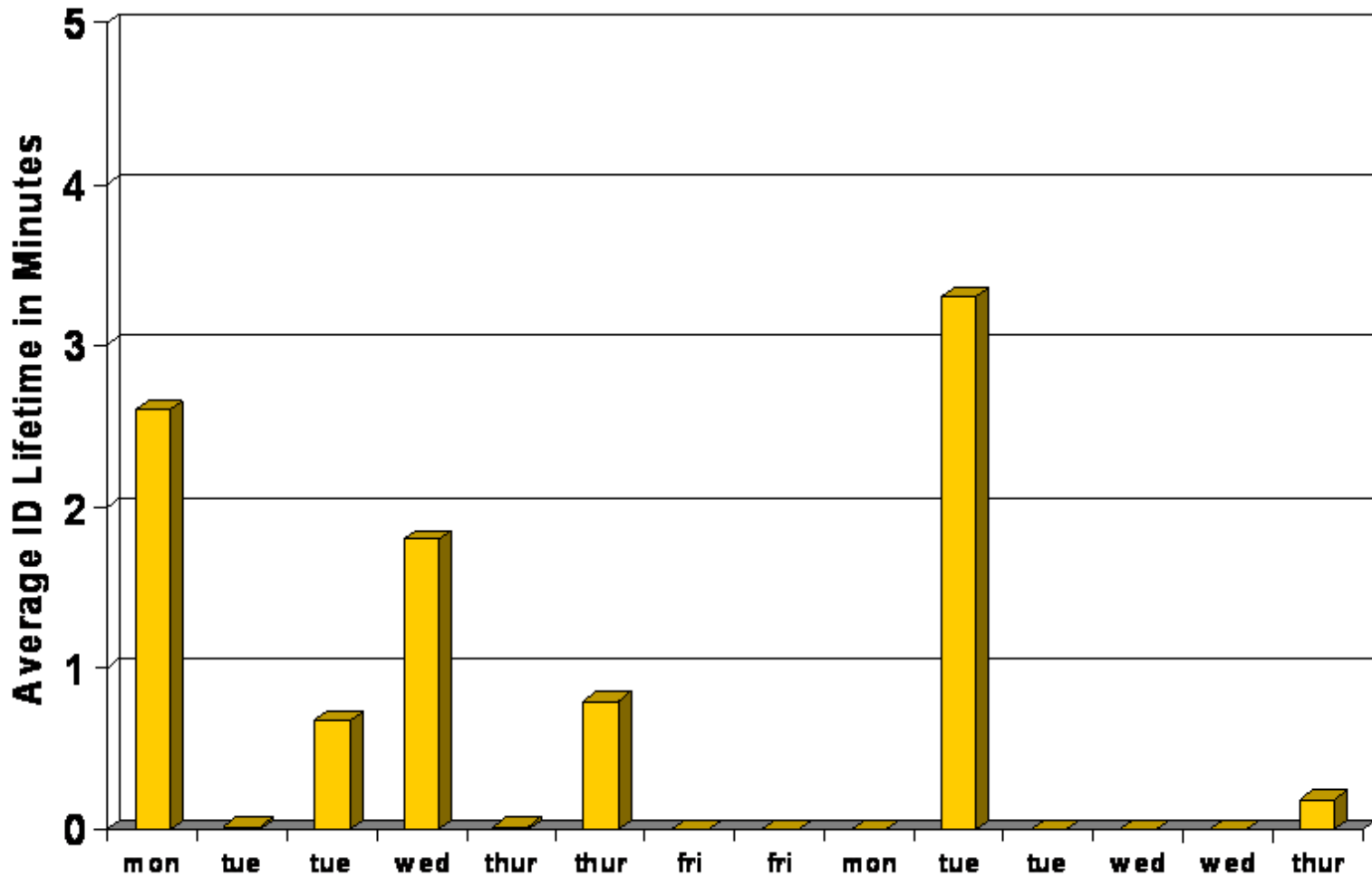
- **The majority of track update messages came from MTIX (67%)**
  - -In one case 2000+ track messages were received for 4 tracks.

- **The majority of targets tracked came from TMSS:**
  - **TMSS (28%), HORIZON (24%), and MTIX (17%)**

- **The majority of threat targets tracked came from TMSS :**
  - **- TMSS (40%), MTIX (24%), and HORIZON (21%)**
  - **- In one case 1 operator track switched between 19 red targets.**

MPTE Experiment – Tracker Maturation

- Real-Time Fusion & Exploitation at Palmdale.
- Coordinated ISR collection.
- Dynamic re-tasking demonstrated.
- 3 Data collects over 3 days. 34 inst. targets.
- Ground-based emphasis for evaluation & analysis.

Palmdale

Satellite

SCDL-ovr-SATCOM

MST — **GCN**

MST — **JSWS** MHT — Mot, atech

GPS

JSTARS-EX

MHT trks

JSTARS-EX, U2-EX KAT trks

JSTARS-EX, U2-EX MHT trks

KAT trks

MTIX KAT

U2-EX, GPS time

AFRL XLTR — AFRL, Black River

U2-NITF

DGS — Raytheon

MIST — Lock-Mart

NITF ovr CDL
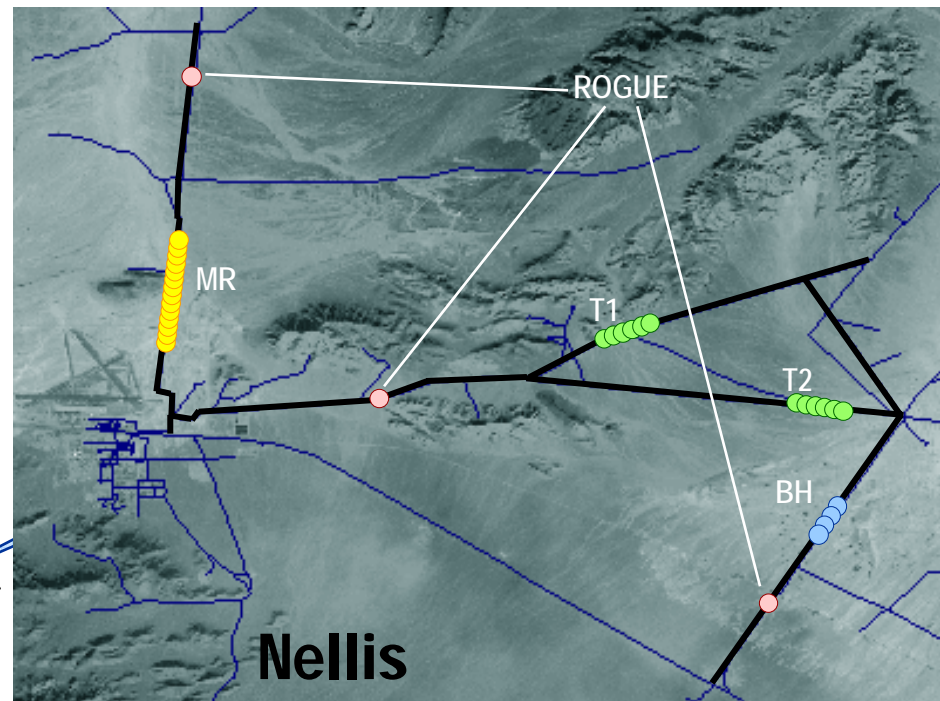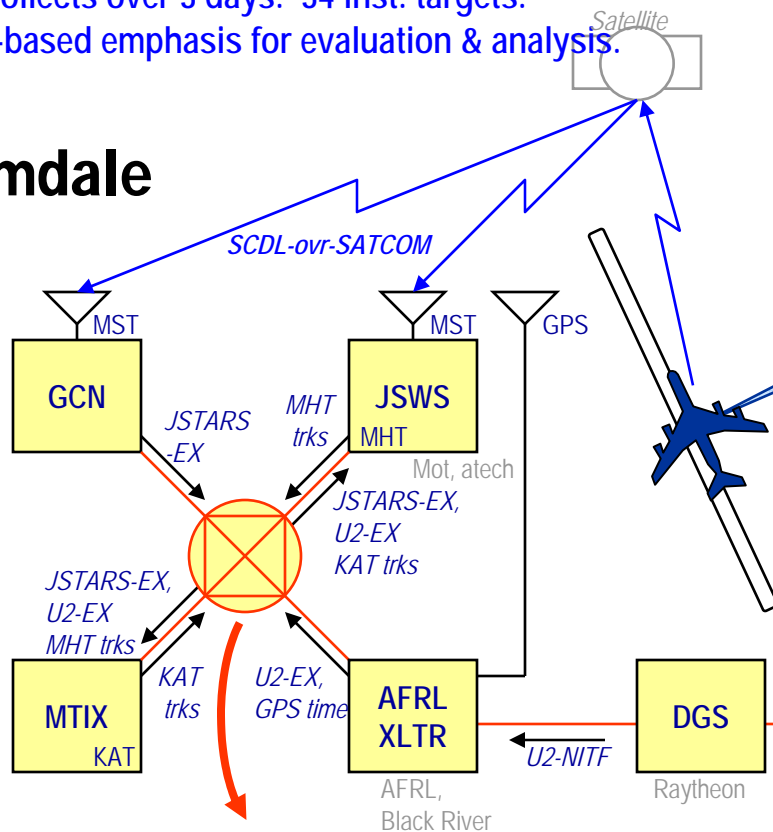
GMTI collected on GROUND network

ROGUE

MR

T1

T2

BH

Nellis

MPTE program serves as tracking benchmark in 2001.

13

Sample Data

Platform 1

Measurements very accurate with quick revisits. Bias correction attempted during experiment. More systematic approach during track evaluation phase.

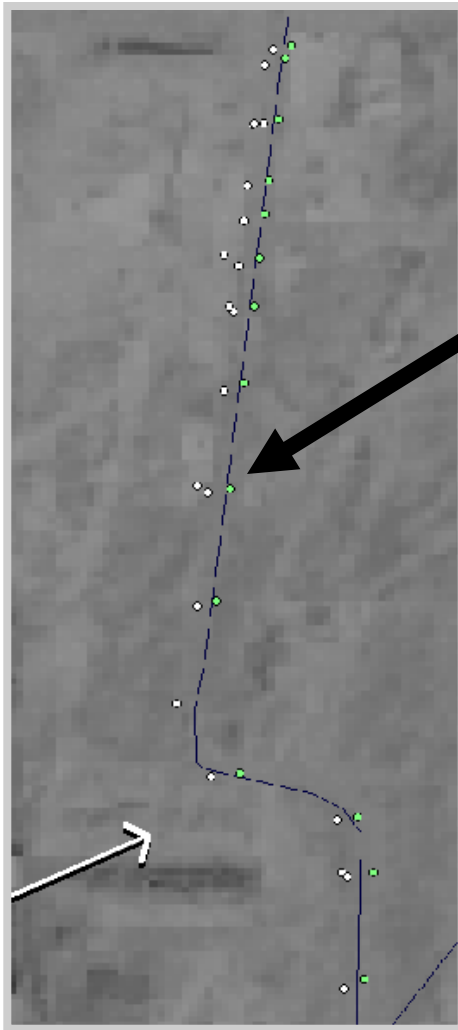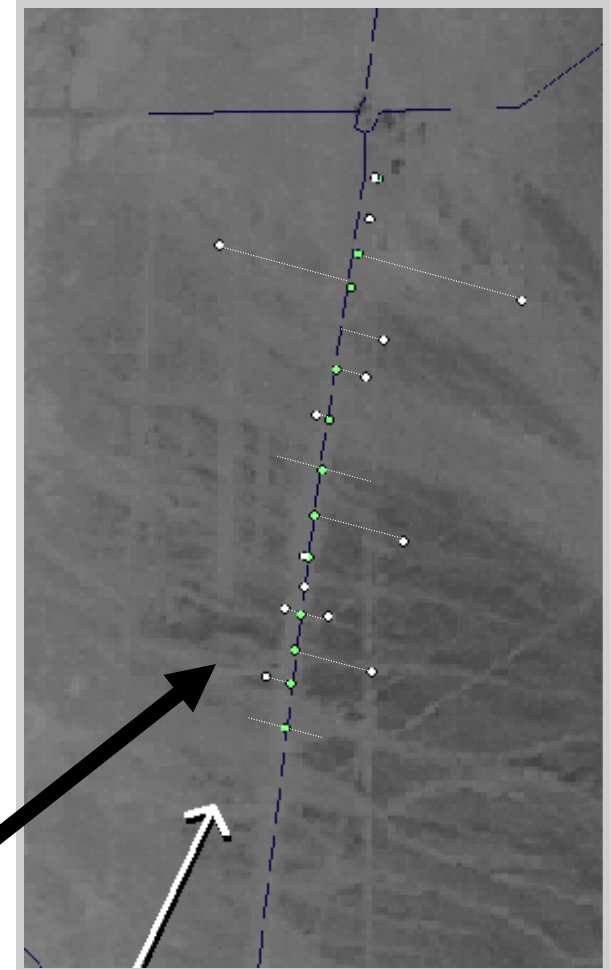*Range measurement very accurate with larger cross-range error expected (smaller antenna). No bias apparent.*

Platform 2

Single Target - Probability of Tracking

Single Target Prob. Of Tracking Without a Switch or a Drop.

Gap Times (seconds)

Track Identity Lifetime (TIL)

Mean: 3.6
1-Sig: 3.0
Median: 2.8
25%: 1.2
75%: 5.3

3.6 Minute Average TIL

Total Track Lifetime (TTL)

Mean: 6.4
1-Sig: 5.2
Median: 5.3
25%: 2.1
75%: 9.1

6.4 Minute Average TTL*

Detections in Track

Target Errors

$Track_B$

$Truth_1$

Pedigree Truth-to-Track

$Track_A$

$Truth_2$
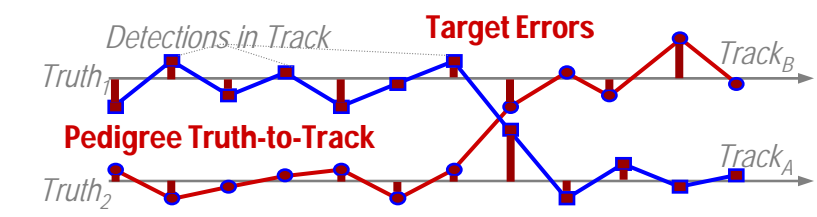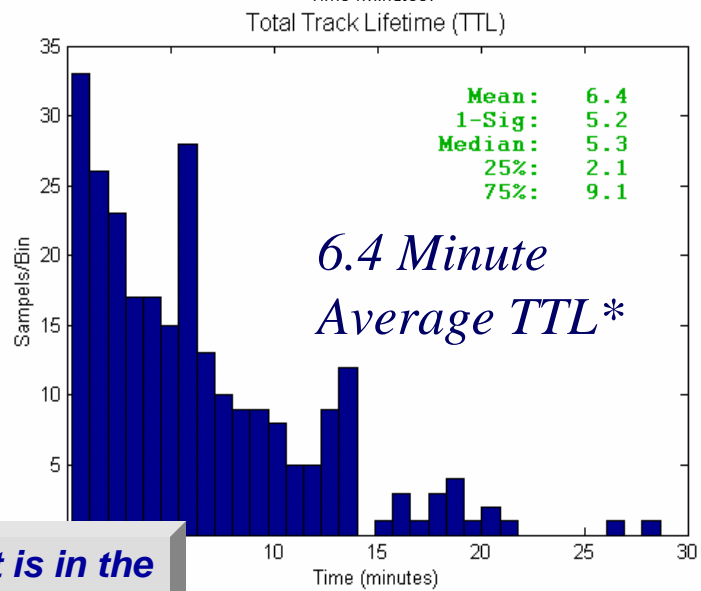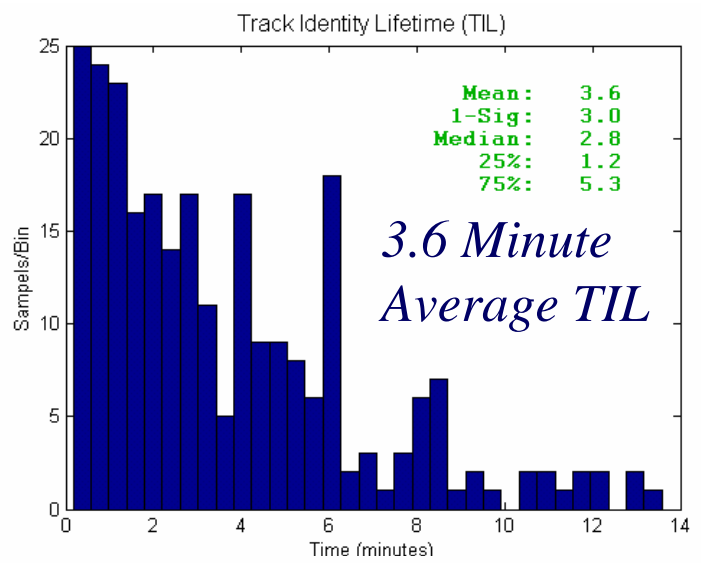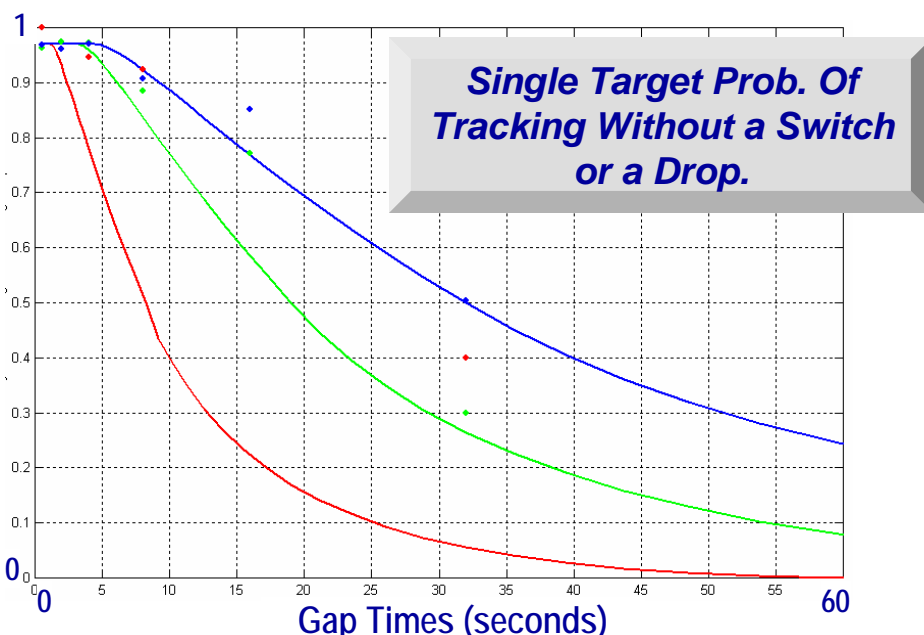
Total Track Lifetime include track switching

Track Identity Lifetime excludes track switching

Results Show What is Now Called _Tracklets_

This is what is in the Track Data Base

Affordable Moving Surface Target Engagement (AMSTE)

Network Centric Architecture

AMSTE Data Fusion System Architecture

Dual Radar Commands

Radar Subsystem 1

Mode Ctrl 1

GMTI, HRR, HUR Requests

Moving Ground Target

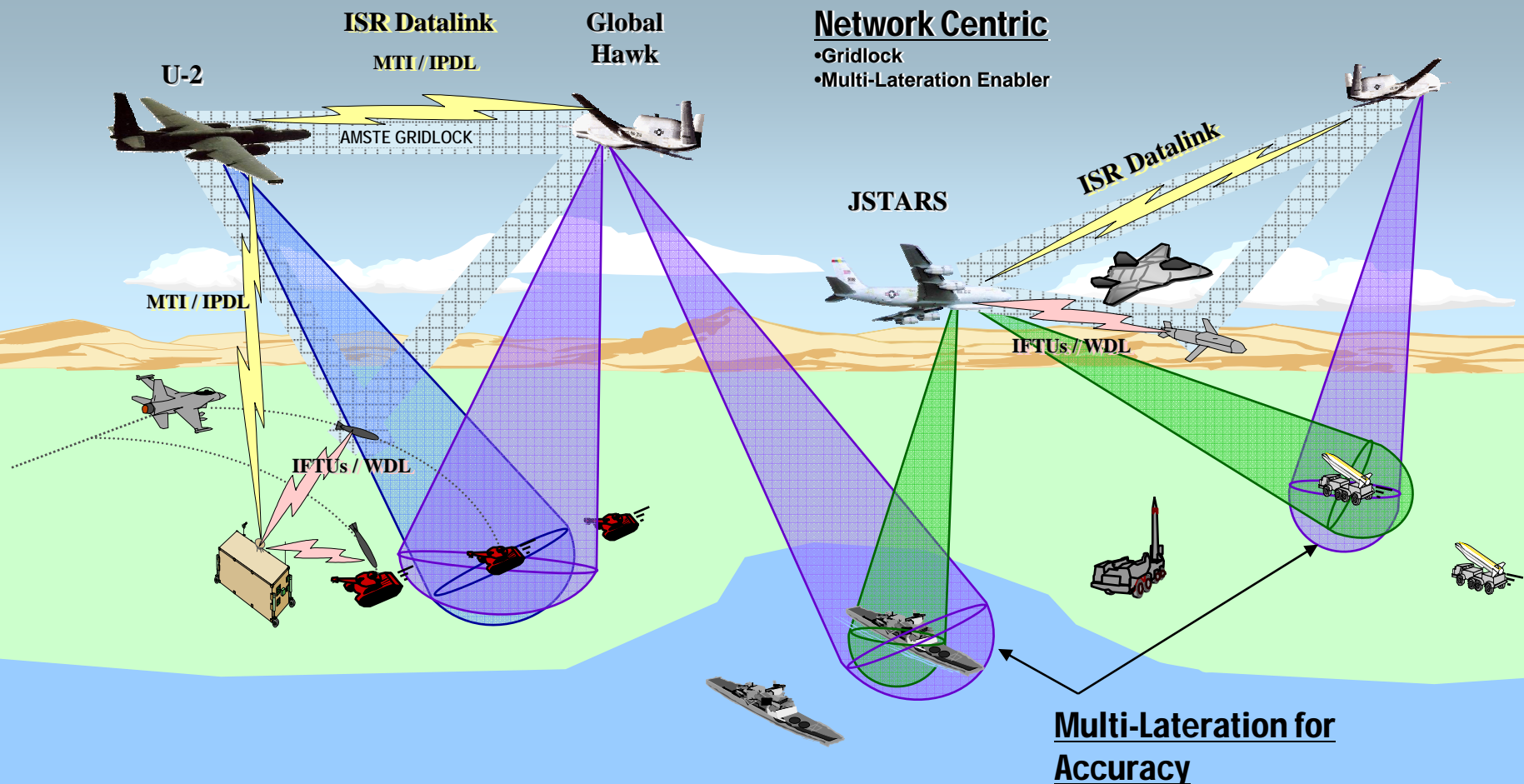**DATA FUSION SUBSYSTEM** (DFS)

Inputs from Dual ISR Radars

GMTI & HRR Reports, A/C state, Sensor Status

Radar Data 1

Sensor Resource Manager

Nomination & Control Commands

Operator

Fused Track Reports

Multiple Hypothesis Tracker

Feature-Aided Track Stitcher

Radar Data 2

In-Flight Track Updates

ISR Data Link

Mode Ctrl 2

GMTI, HRR, HUR Requests

Radar Subsystem 2

Weapon Updates

Given ISR GMTI detections, the challenge is Long Term Track Maintenance (>20 min.)

The DFS accepts ISR radar data and operator commands, and controls the weapon aimpoint and both radar systems.

- October 7th and 9th

- 6 Convoys
  - 2-6 Vehicles each

- Events
  - Passing
  - Intersection
  - Move-Stop-Move
  - On-Off Road
  - Terrain Blockage

- Features
  - HRR
  - RCS
  - TEA
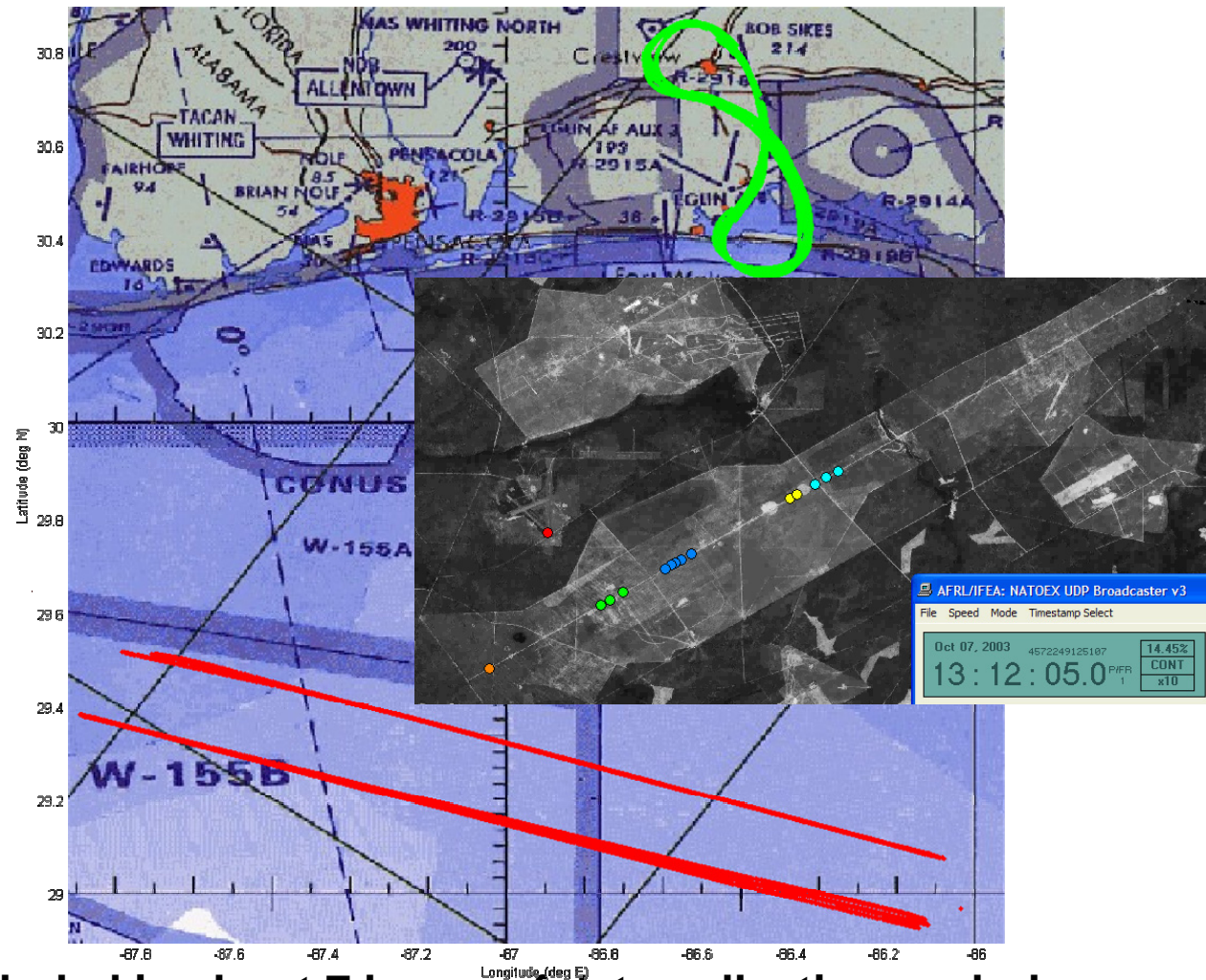
17 Scenarios included in about 7 hours of data collection each day

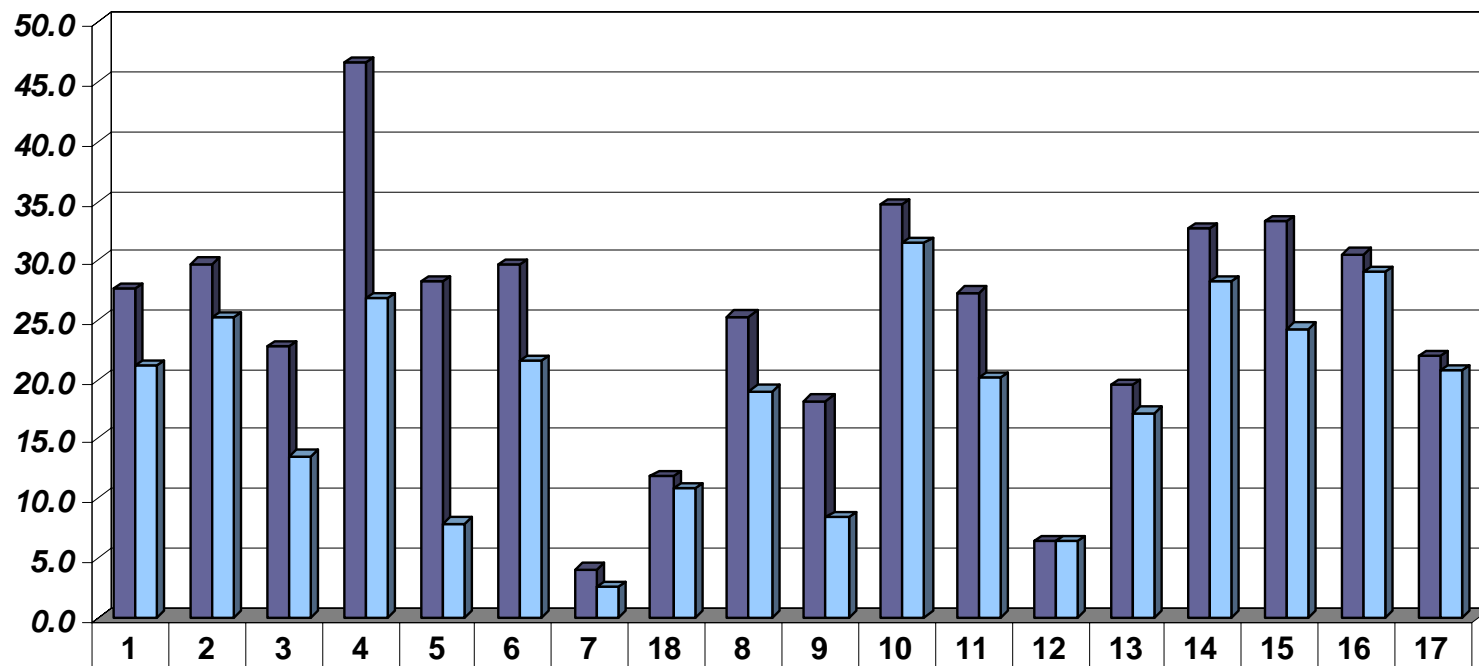**Each Confusion Event is Scored Based on Difficulty**

07-October, 2003   Flight 506   Nomination Duration & Track Lifetime (Adj.)

	1	2	3	4	5	6	7	18	8	9	10	11	12	13	14	15	16	17
■ Nomination Duration	27.6	29.8	22.7	46.6	28.3	29.6	4.0	11.8	25.3	18.2	34.7	27.4	6.4	19.6	32.7	33.3	30.5	21.9
■ Adjusted Lifetime	21.2	25.2	13.6	26.9	7.9	21.6	2.5	10.9	19.0	8.4	31.5	20.2	6.4	17.2	28.2	24.3	29.1	20.7

(with and without manual intervention)

07-October, 2003   Flight 506

Mean w/MIL 22.3

Mean w/o 7.2

	1	2	3	4	5	6	7	18	8	9	10	11	12	13	14	15	16	17
☐ TIL - No Man. (min)	15.2	7.3	1.8	5.9	7.4	8.7	2.7	1.3	6.4	6.7	14.8	7.2	3.1	2.9	7.8	4.3	10.4	16.5
■ TIL - w/ Man. (min)	25.8	30.5	17.4	31.3	7.4	27.3	2.7	12.8	24.9	18.7	33.4	20.5	6.1	19.2	31.5	31.1	33.5	28.3
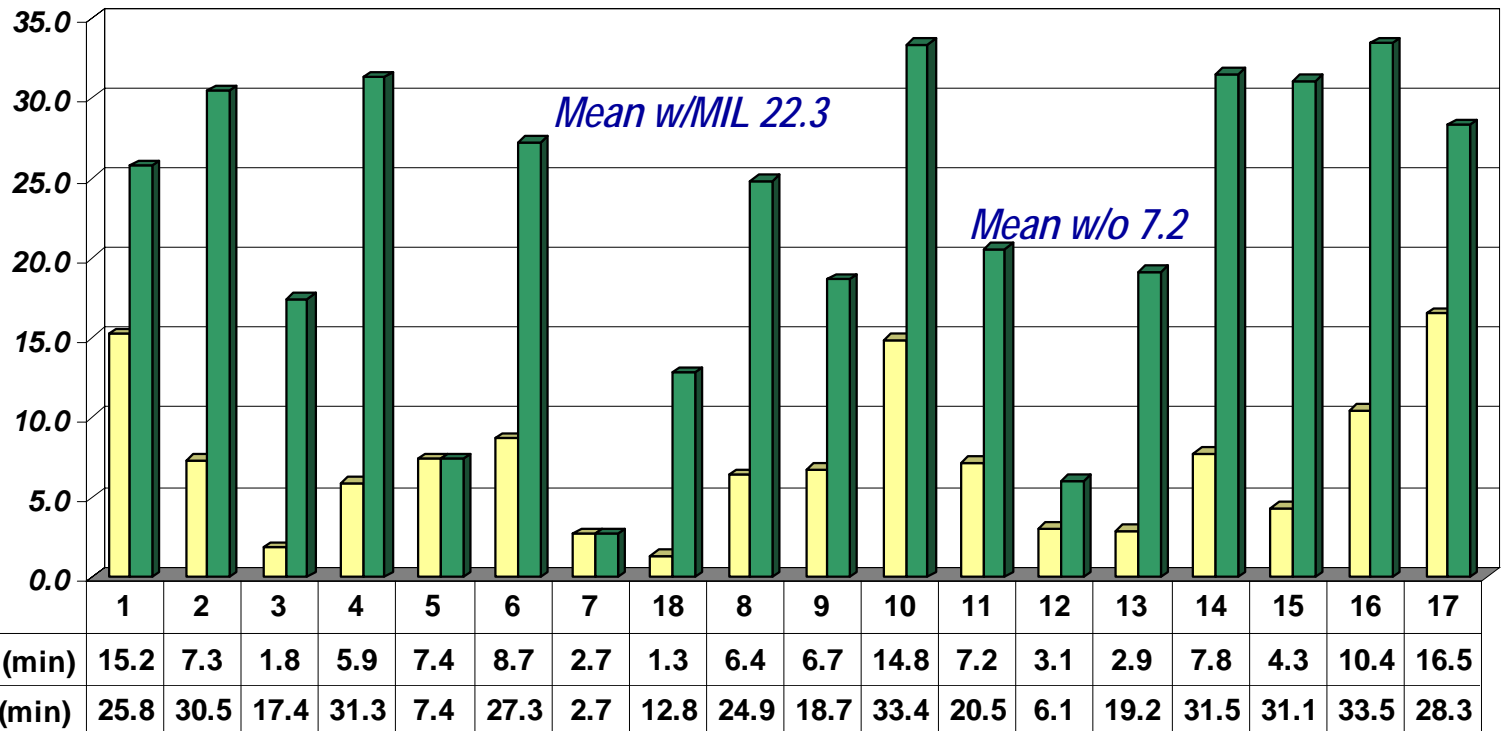
Weapon Drop

• F16 ~ 5 miles range

• Live JDAM, GPS Guided

• EPLRS Weapon Data Link

•EPLRS Inter Platform Comm.

•GMTI Coord. Passed to Weapon In Flight from JSTARS

Multi-Platform Fusion of GMTI Achieves Accuracy

Summary

- **GMTI Tactical Grade Tracking is "Hard"**
  - Well Defines Measures of Performance
  - State of the Art is Improving
  - Requires Significant Resources

- **State of the Art in Improving**
  - MPTE achieved 3.6 minutes
  - AMSTE improved this to 7.2 Minutes

- **Situation Awareness Metrics need Maturing**
  - Operator in the Loop Measures Provide a Unique Result
  - Tracks are only performing "Book Keeping"
  - Detections Provide Some Unique "Pattern Analysis"